



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/EP96/01234 <b>(22) International Filing Date:</b> 19 March 1996 (19.03.96) <b>(30) Priority Data:</b> 95200673.2      20 March 1995 (20.03.95)      EP <b>(34) Countries for which the regional or international application was filed:</b> GB et al.  <b>(71) Applicant (for all designated States except CA):</b> SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V. [NL/NL]; Carel van Bylandtlaan 30, NL-2596 HR The Hague (NL).  <b>(71) Applicant (for CA only):</b> SHELL CANADA LIMITED [CA/CA]; 400 - 4th Avenue S.W., Calgary, Alberta T2P 2H5 (CA).  <b>(72) Inventors:</b> KOELMAN, Johannes, Maria, Vianney, Antonius; Volmerlaan 6, NL-2288 GD Rijswijk (NL). DE KUIJPER, Andre; Volmerlaan 6, NL-2288 GD Rijswijk (NL).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
<b>(54) Title:</b> DETERMINING A PARAMETER OF A COMPONENT IN A COMPOSITION		
<b>(57) Abstract</b> <p>A method of determining a parameter selected from the electrical conductivity and the volume fraction of a component in a composition comprising a plurality of components is provided. The method comprises measuring the electrical conductivity of the composition, and selecting a relationship between the conductivity of the composition and a plurality of composition parameters including, for each component, physical parameters representing the conductivity and the volume fraction of the component, said relationship being such that the components are substantially equally represented in said relationship by means of said physical parameters. The selected parameter of the component in the composition is determined from said relationship and the measured conductivity of the composition.</p>		

DETERMINING A PARAMETER OF A  
COMPONENT IN A COMPOSITION

The present invention relates to a method of determining a parameter selected from the electrical conductivity and the volume fraction of a component in a composition comprising a plurality of components. The invention is of particular interest for determining the volume fraction of a component of an earth formation, for example to determine the hydrocarbon-content of a hydrocarbon bearing earth formation. Various known methods of determining such content have been applied until now, which known methods are generally based on empirical models.

One such known method is described in "Electrical conductivities in oil-bearing shaly sands", Waxman M.H. and Smits L.J.M., SPE paper 1863-A presented at 42nd Ann. Fall Meeting, Houston, October 1-4, 1967.

This publication discloses a method of determining a parameter selected from the electrical conductivity and the volume fraction of a component in a composition comprising a plurality of components, wherein the electrical conductivity of the composition is measured, and a relationship between the conductivity of the composition and the conductivity of a component is selected.

This known method uses the following relationship which is generally referred to as the Waxman-Smits model:

$$C_o = C_w / F^* + BQ_v / F^*$$

where  $C_o$  = conductivity of fully brine saturated rock  
 $C_w$  = conductivity of brine present in the formation

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$F^*$  = a formation factor

$B$  = equivalent conductance of sodium clay-exchange cations as a function of  $C_w$

$Q_v$  = cation exchange capacity per unit pore volume.

5 The results achieved with this known method are not always sufficiently accurate, probably because of the empirical nature of the Waxman-Smiths model which provides a relationship between the earth conductivity and the various other parameters.

10 It is an object of the invention to provide a more accurate method of determining a parameter selected from the electrical conductivity and the volume fraction of a component in a composition comprising a plurality of components.

15 The method according to the invention thereto comprises:

- measuring the electrical conductivity of the composition;
- selecting a relationship between the electrical conductivity of the composition and a plurality of composition parameters including, for each component, physical parameters representing the electrical conductivity and the volume fraction of the component, the components being substantially equally represented in said relationship by means of said physical parameters;
- 20 and
- determining said selected parameter from said relationship and the measured conductivity of the composition.

25  
30 It is to be understood that by the electrical conductivity is meant the electrical conductivity itself or any quantity derived therefrom, such as the electrical resistivity. Furthermore, the feature that the components are substantially equally represented in the relationship  
35 implies that each component is represented in the

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relationship in substantially the same way as any other of the components.

With the method according to the invention it is achieved that results of increased accuracy are provided. The selected relationship takes accurately account of the individual contributions of the components to the conductivity of the composition. The relationship applied in the method according to the invention is symmetrical in the components, i.e. no component is favoured over another component. Moreover, it was found that the method according to the invention provides the desired accuracy for any percolation threshold of the components. In this respect it is to be understood that the amount of percolation of a component refers to the degree of continuity of the component in the composition. For example, vanishing percolation of a component implies that the component is fully dispersed in the composition, and full percolation of a component implies that the component is continuous throughout the composition.

Advantageously said plurality of composition parameters includes at least one fitting parameter, and wherein each fitting parameter is determined by applying said relationship to a data set obtained by measuring the electrical conductivity of at least one sample representative for said composition for various magnitudes of at least one of said parameters.

Preferably said plurality of parameters includes an auxiliary parameter depending on the geometrical configuration of the components in the composition.

Accurate geometrical representation by the auxiliary component is achieved if said auxiliary parameter is selected so as to be a function of a plurality of variables, each variable depending on the conductivity of one of said components and a mixing coefficient, whereby

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the mixing coefficients depend on the geometrical configuration of the components in the composition.

Advantageously the step of determining each fitting parameter by applying said relationship to the data set  
 5 of the component is carried out through an iterative process. Suitably the iterative process includes repeatedly applying said relationship in a minimisation scheme. The minimisation scheme is preferably applied to  
 10 an incoherence between the measured electrical conductivities of said components and the electrical conductivities of the components as determined through said relationship.

The invention will be described hereinafter in more detail and by way of the following example and  
 15 comparative example.

#### Example

Consider an isotropic system with essential spherical inclusions in the form of an earth formation which essentially consists of four components: non-conducting  
 20 porous rock matrix, non-conducting hydrocarbon fluid, conducting clay, and conducting brine. The conductivity of the formation depends on the fractional brine saturation of the pore space, and the hydrocarbon fluid component is grouped with the rock matrix, both being  
 25 non-conducting. Thus, the hydrocarbon component and the rock matrix component only enter the equations with the sum of their volume fractions. The effective conductivity  $\sigma_{\text{eff}}$  of this earth formation is evaluated through the expression

$$\frac{(\sigma_{\text{eff}} - \sigma_0) \cdot (L\sigma_{\text{eff}} + (1-L)\sigma_0)^{-1}}{(L\sigma_k + (1-L)\sigma_0)^{-1}} = \sum \phi_k (\sigma_k - \sigma_0).$$

30 wherein  $\sigma_0$  represents the auxiliary parameter in the form of a conductivity tensor

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$k = 1 \dots N$ ,  $N$  being the number of components  
 $\sigma_{\text{eff}}$  represents the conductivity tensor of the sample  
 $\sigma_k$  represents the conductivity tensor of component  $k$   
 $\phi_k$  represents the volume fraction of component  $k$   
5  $L$  represents the depolarisation tensor (shape  
tensor)

Preferably the depolarisation tensor is positive and  
has unit trace. In an attractive embodiment the  
depolarisation tensor equals  $1/3$  times the unit tensor.

10 The term  $\sigma_0$  denotes an auxiliary parameter which can  
be thought of as being an additional host medium into  
which components are added until the host medium has been  
completely replaced by the components so that no volume  
fraction is associated with the host medium. The  
15 existence of the host medium enables the model to be  
symmetrical in all its constituents: none of the  
components rock, clay or brine in the model is favoured  
over any of the other components. The dependence of  $\sigma_0$  on  
various parameters, yet to be determined, governs the  
20 percolation behaviour of the model. Setting  $\sigma_0 = \sigma_{\text{brine}}$   
leads to the known Average T-matrix Approximation, also  
referred to as the generalised Clausius-Mossotti  
equation. This model has a clear asymmetry between the  
brine component and the other components since only the  
25 brine component will percolate, irrespective of its  
volume fraction. Selecting a self-consistent host medium  
conductivity,  $\sigma_0 = \sigma_{\text{eff}}$ , leads to the known Coherent  
Potential Approximation, also referred to as the  
generalised Bruggeman equation. This model is symmetrical  
30 in all components but has the drawback of requiring  
unrealistically high percolation thresholds for each  
component.

In a suitable embodiment, the auxiliary parameter  $\sigma_0$   
is selected as follows:

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$$\sigma_0 = \sum h_k \sigma_k ; \text{ for } k = 1, 2, 3$$

wherein  $h_k$  represents the mixing coefficient tensor  
 pertaining to component  $k$ , which tensor contains mixing  
 5 coefficients representing geometrical information on the  
 spatial distribution of the components in the formation.  
 These coefficients determine the connectivity, i.e. the  
 amount of percolation of the individual components. The  
 coefficients are non-negative and fulfil the  
 10 normalisation condition:

$$\sum h_k = 1; \text{ for } k = 1, 2, 3$$

The normalisation relation ensures that the resulting  
 15 effective conductivity  $\sigma_{\text{eff}}$  satisfies the Hashin -  
 Shtrikman bounds, which are well known to those skilled  
 in the art.  
 Furthermore, a component with a vanishingly small volume  
 fraction can not percolate, hence the corresponding  
 20 connectivity parameter should vanish:

$$\lim h_k = 0; \text{ for } \phi_k \Rightarrow 0$$

Suitably the mixing coefficient tensor is selected to  
 be

$$h_k = \lambda_k \phi_k^{\nu_k} (\sum \lambda_n \phi_n^{\nu_n})^{-1}$$

wherein  $k, n = 1 \dots N$ ,  $N$  being the number of  
 components in said plurality of components  
 25  $\lambda_k$  represents the percolation rate tensor pertaining  
 to component  $k$   
 $\phi_k$  represents the volume fraction of component  $k$   
 $\nu$  represents the percolation exponent pertaining to  
 component  $k$

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Suitably at least one of  $h_k$ ,  $\lambda_k$  and  $v$  forms a fitting parameter.

A data set on 27 shaly-sand core samples has been used to test the invention, which data set is described in the above indicated SPE paper. This publication provides  $C_o - C_w$  curves on the core samples ranging from almost clean sand ( $Q_v = 0.017$  eq/l) to extremely shaly sand ( $Q_v = 1.47$  eq/l). The samples contained Kaolinite, Montmorillonite and Illite, either in combination or separately in each sample. The characteristic petrophysical data of each sample are listed in the appended Table, in which  $\phi$  denotes the porosity of the sample,  $k$  denotes the permeability of the sample, and  $Q_v$  denotes the cation exchange capacity per unit pore volume of the sample. The conductivity of each sample in fully brine saturated condition was measured for eight to ten salinities of the brine. Furthermore, concentration membrane potential measurements were made of the samples.

The parameters in this model were selected as follows:

1) Brine;

The volume fraction of brine,  $\phi_b$ , is determined by the porosity, the amount of clay-bound water, and the water saturation  $S_w$ . The brine conductivity  $\sigma_b (=C_w)$  is determined by the brine salinity and the brine temperature. The two percolation parameters,  $\lambda_b$  and  $v$ , are free parameters.

2) Rock / Hydrocarbon;

The volume of hydrocarbons,  $\phi_{hc}$ , is determined by the total porosity, the amount of clay-bound water, and the hydrocarbon saturation  $1-S_w$ , while the volume of the rock matrix,  $\phi_r$ , is calculated using the sum rule and the volume fractions. Both the rock and the hydrocarbon have vanishing conductivity. The percolation parameters  $\lambda_r$  and  $\lambda_{hc}$  of both components was set at value 1. The mixing



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coefficient pertaining to rock/hydrocarbon  $h_{r/hc}$  follows from the condition  $\sum h_k = 1$ .

3) Clay;

The volume of clay  $\phi_c$  and the clay conductivity  $\sigma_c$  are free fitting parameters. The percolation rate  $\lambda_c$  was set at a value 0, which is a suitable choice for non-laminated clays. It furthermore appeared that an additional free parameter did not give a significant improvement of the model fit to the data set.

The  $C_o - C_w$  measurements were made for an extreme salinity range, namely a brine salinity between 1 - 300 g/l. For a given sample the brine volume fraction varied only slightly over the whole salinity range. In view thereof the percolation parameter  $v$  was set equal to unity in the test, thereby reducing the percolation parameter  $h_b$  to a constant, and reducing the number of free parameters to three.

For each sample, a fit to the  $C_o - C_w$  curve was made by minimising the relative incoherence defined as:

$$\sum \Delta^2 C_o - C_w = \sum_{\text{salinities}} \left( \frac{C_{o,calc} - C_{o,meas}}{C_{o,meas}} \right)^2$$

wherein

$C_{o,calc}$  = the calculated conductivity of the fully brine saturated rock samples;

$C_{o,meas}$  = the measured conductivity of the fully brine saturated rock samples;

$\sum$  = summation over the salinities.

The results for the three fitting parameters  $\phi_c$ ,  $\sigma_c$  and  $h_b$ , and the relative incoherence are given in the appended Table.

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Furthermore, the Table gives the incoherence between the membrane potential ( $\psi_{\text{calc}}$ ) determined by the method of the invention and the measured membrane potential ( $\psi_{\text{meas}}$ ):

$$\sum \Delta^2_{\text{MP}} = \sum_{\text{salinities}} \left( \frac{\psi_{\text{calc}} - \psi_{\text{meas}}}{\psi_{\text{meas}}} \right)^2$$

The membrane potential is a particularly interesting quantity for being a direct, non-destructive, measure of the clay contribution to the overall conductivity, which has not been used to determine the fitting parameters.

To illustrate the invention more specifically, reference is made to the following comparative example.

Comparative example

As stated above Ref. 1 discloses, apart from the data set on the 27 core samples, furthermore an empirical model which is generally referred to as the Waxman-Smits model. To compare the method according to the invention with the Waxman-Smits model, the relative incoherence between the measured conductivities and the conductivities found from the Waxman-Smits model, and the relative incoherence between the measured concentration membrane potentials and the concentration membrane potentials found from the Waxman-Smits model, were determined. These relative incoherences for all 27 samples are listed in the Table. In applying the Waxman-Smits model, use has been made of the well known expression:

$$C_o = C_w / F^* + BQ_v / F^*$$

with  $F^* = \phi^{-m}$

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where  $m$  is a free parameter (also referred to as the cementation exponent),  $Q_v$  is determined from sample measurements, just as the porosity  $\phi$ , and the standard B-chart has been used to calculate the salinity and temperature effects on the conductivity measurements.

From a comparison between the incoherence values found by using the method according to the invention, and the incoherence values found by using the Waxman-Smiths model, it is clear that the method according to the invention provides improved results. Especially the extremely low incoherence values for the concentration membrane potential, which values are moreover fairly constant over the entire  $Q_v$  range, indicates that the method according to the invention provides results of increased accuracy.

The method according to the invention can suitably be applied to determine the volume fraction of brine or hydrocarbon in an earth formation, whereby a well-log representing the electrical conductivity of the formation is provided. Such application can, for example, be carried out in the following manner. The well-log of the electrical conductivity of the earth formation is made using a logging tool lowered in a borehole formed in the earth formation. For an isotropic formation with components brine (subscript B), clay (subscript C), and non-conducting rock + hydrocarbon (subscript R/HC) the rock and the hydrocarbon are grouped together because of their vanishing conductivities. The selected relationship then is:

$$\frac{\sigma_{\text{eff}} - \sigma_0}{\sigma_{\text{eff}} + 2\sigma_0} = \sum_{k=1}^3 \phi_k \cdot \frac{\sigma_k - \sigma_0}{\sigma_k + 2\sigma_0}$$

wherein

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$$\sigma_0 = \sum h_k \sigma_k$$

$$h_k = \lambda_k \phi_k^{v_k} (\sum \lambda_n \phi_n^{v_n})^{-1}$$

in which

$\sigma_0$  represents the auxiliary parameter

$k$ ,  $n = 1 \dots N$ ,  $N$  being the number components

$\sigma_{\text{eff}}$  represents the conductivity of the earth formation

5  $\sigma_k$  represents the conductivity of component  $k$

$\phi_k$  represents the volume fraction of component  $k$

$h_k$  represents the mixing coefficient pertaining to component  $k$ ;

10  $\lambda_k$  represents the percolation coefficient pertaining to component  $k$

$v_{k,n}$  represents the percolation exponent pertaining to component  $k$ ,  $n$

Each component  $k$  has four parameters:  $\phi_k$ ,  $\sigma_k$ ,  $\lambda_k$ , and  $v_k$ , of which  $\phi_B$ ,  $\sigma_B$  and  $\sigma_{R/HC}$  are directly measured.

15 Furthermore,  $\lambda_C = 0$  for dispersed clay. From the sum rules  $h_{R/HC}$  and  $\phi_{R/HC}$  follow. Parameters which are yet to be determined are  $\sigma_C$ ,  $\lambda_B$ ,  $v_B$  and  $\phi_C$ . These parameters are determined through forward modelling on experimental data.  $\sigma_C$ ,  $\lambda_B$  and  $v_B$  are invariable over the geological formation, while  $\phi_B$  will be depth dependent. The experimental data for the parameter determination consist of well-log measurements from a brine containing zone, laboratory Formation Resistivity Factor (FRF)

20 measurements and brine saturation experiments. The log information from the brine containing zone is used to correlate the local parameter  $\phi_C$  to suitable logs/log combinations, as is known to those skilled in the art of well logging.  $\sigma_C$ ,  $\lambda_B$  and  $\phi_B$  and the correlation of  $\phi_C$  to suitable logs/log combinations can be used in hydrocarbon bearing formations. From the well-log, the above

30 relationship and the indicated parameters, the volume

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faction of brine and thus also the volume fraction of hydrocarbon is determined as a function of depth.

sample No.	petrophysical data			parameters			incoherence for present invention	incoherence for prior art
	$\phi$	$\kappa$ [mD]	$Q_v$ [eq/l]	$\varphi_c$	$\sigma_c$ [mS/cm]	$h_B$	$\sum \Delta_{c-o}^2$	$\sum \Delta_{\psi}^2$
1	0.239	659	0.017	0.0532	2.9581	0.2016	0.002	0.018
2	0.212	105	0.052	0.1822	1.3537	0.2038	0.002	0.035
3	0.231	397	0.052	0.1376	1.8607	0.2517	0.002	0.014
4	0.080	1.34	0.26	0.1323	1.3325	0.1788	0.010	0.119
5	0.154	55	0.2	0.3216	1.4851	0.3752	0.005	0.042
6	0.215	29	0.095	0.3467	1.0193	0.1370	0.003	0.026
7	0.171	3.5	0.053	0.3779	0.7847	0.1200	0.008	0.016
8	0.171	7.66	0.053	0.3119	0.8994	0.1274	0.007	0.018
9	0.199	57	0.085	0.3935	1.0627	0.1613	0.007	0.025
10	0.125	0.042	0.253	0.432	0.3113	0.0255	0.029	0.074
11	0.125	0.0106	0.253	0.4007	0.2590	0.0233	0.037	0.057
12	0.110	1.86	0.28	0.5855	0.8601	0.1326	0.018	0.010
13	0.110	0.3	0.28	0.5998	1.0802	0.1286	0.020	0.016
14	0.110	2.08	0.28	0.5815	1.4104	0.1998	0.054	0.029
15	0.092	0.128	0.41	0.509	0.6025	0.0402	0.027	0.025
16	0.103	0.024	0.67	0.7202	1.4537	0.1103	0.010	0.013
17	0.140	0.575	0.33	0.7763	1.5783	0.0977	0.050	0.013
18	0.259	3.78	0.59	0.7033	2.8964	0.1357	0.012	0.007
19	0.259	17.1	0.59	0.6408	2.8227	0.1484	0.010	0.012
							0.823	0.376

sample No.	petrophysical data			parameters			incoherence for present invention		incoherence for prior art	
	$\phi$	$\kappa$ [mD]	$Q_v$ [eq/l]	$\varphi_c$	$\sigma_c$ [mS/cm]	$h_B$	$\sum \Delta_{c_0-c_v}^2$	$\sum \Delta_\psi^2$	$\sum \Delta_{c_0-c_v}^2$	$\sum \Delta_\psi^2$
20	0.259	44.8	0.59	0.5978	3.4771	0.2113	0.003	0.023	0.674	0.286
21	0.238	315	0.29	0.6984	1.3859	0.1812	0.009	0.031	0.632	0.546
22	0.225	1.92	0.72	0.7651	2.4172	0.0766	0.016	0.013	1.808	0.637
23	0.242	54.3	1.04	0.7306	4.0758	0.1165	0.022	0.011	1.640	0.490
24	0.216	0.546	0.81	0.7751	2.6418	0.0659	0.021	0.014	2.103	0.703
25	0.187	0.0348	1.27	0.7995	3.4510	0.0726	0.005	0.040	0.490	0.369
26	0.229	1.53	1.47	0.7491	5.0425	0.0887	0.042	0.026	2.155	0.470
27	0.209	0.263	1.48	0.7656	5.1455	0.0884	0.001	0.067	0.495	0.326

TABLE

C L A I M S

1. A method of determining a parameter selected from the electrical conductivity and the volume fraction of a component in a composition comprising a plurality of components, the method comprising:
- 5       - measuring the electrical conductivity of the composition;
- selecting a relationship between the electrical conductivity of the composition and a plurality of composition parameters including, for each component,
- 10       physical parameters representing the electrical conductivity and the volume fraction of the component, the components being substantially equally represented in said relationship by means of said physical parameters; and
- 15       - determining said selected parameter from said relationship and the measured conductivity of the composition.
2. The method of claim 1, wherein said plurality of composition parameters includes at least one fitting
- 20       parameter, and wherein each fitting parameter is determined by applying said relationship to a data set obtained by measuring the electrical conductivity of at least one sample representative for said composition for various magnitudes of at least one of said parameters.
- 25       3. The method of claim 1 or 2, wherein said plurality of parameters includes an auxiliary parameter depending on the geometrical configuration of the components in the composition.
- 30       4. The method of claim 3, wherein said relationship is selected to be



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$$(\sigma_{\text{eff}} - \sigma_0) \cdot (L\sigma_{\text{eff}} + (1-L)\sigma_0)^{-1} = \sum \phi_k (\sigma_k - \sigma_0) \cdot (L\sigma_k + (1-L)\sigma_0)^{-1}$$

wherein  $\sigma_0$  represents the auxiliary parameter in the form of a conductivity tensor

$k = 1 \dots N$ ,  $N$  being the number components

$\sigma_{\text{eff}}$  represents the conductivity tensor of the sample

$\sigma_k$  represents the conductivity tensor of component  $k$

$\phi_k$  represents the volume fraction of component  $k$

$L$  represents a depolarisation tensor

5. The method of claim 3 or 4, wherein said auxiliary parameter is selected so as to be a function of a plurality of variables, each variable depending on the conductivity of one of said components and a mixing coefficient, whereby the mixing coefficients depend on the geometrical configuration of the components in the composition.

6. The method of any of claims 3-5, wherein said auxiliary parameter is selected to be

$$\sigma_0 = \sum h_k \sigma_k$$

wherein  $\sigma_0$  represents the auxiliary parameter in the form of a conductivity tensor representative for the conductivity in the three principal directions;

$k = 1 \dots N$ ,  $N$  being the number of components;

$\sigma_k$  represents the conductivity tensor of component  $k$ ;

$h_k$  represents the mixing coefficient tensor pertaining to component  $k$ ;

7. The method of claim 5 or 6, wherein said mixing coefficients are selected so that the sum of the mixing coefficients substantially equals unity.

8. The method of any of claims 5-7, wherein said mixing coefficients are non-negative.

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9. The method of any of claims 5-8, wherein each mixing coefficient is selected to be a function of at least the volume fraction of the component pertaining to said mixing coefficient.

5 10. The method of claim 9, wherein said function is a monotonous increasing function in the volume fraction of the component pertaining to the mixing coefficient.

11. The method of claim 9 or 10, wherein said function is selected so that the mixing coefficient vanishes for  
10 vanishing volume fraction of the component pertaining to the mixing coefficient.

12. The method of any of claims 5-11, wherein each mixing coefficient is selected as

$$h_k = \lambda_k \phi_k^{v_k} (\sum \lambda_n \phi_n^{v_n})^{-1}$$

15 wherein  $k, n = 1 \dots N$ ,  $N$  being the number components in said plurality of components

$\lambda_k$  represents a percolation rate tensor pertaining to component  $k$

$\phi_k$  represents the volume fraction of component  $k$

20  $v_{k,n}$  represents a percolation exponent pertaining to component  $k, n$

13. The method of claim 12, wherein at least one of  $h_k$ ,  $\lambda_k$  and  $v$  forms a fitting parameter.

14. The method of any of claims 4-13, wherein the  
25 depolarisation tensor is positive.

15. The method of any of claims 4-14, wherein the depolarisation tensor has unit trace.

16. The method of any of claims 4-15, wherein the depolarisation tensor equals 1/3 times the unit tensor.

30 17. The method of any of claims 1-16, wherein the step of determining each fitting parameter by applying said relationship to the data set is carried out through an iterative process.

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18. The method of claim 17, wherein the iterative process includes repeatedly applying said relationship in a minimisation scheme.

5 19. The method of claim 18, wherein the minimisation scheme is applied to a mismatch between the measured electrical conductivities of said components and the electrical conductivities of the components as determined through said relationship.

10 20. The method of any of claims 1-19, wherein said composition includes an earth formation.

21. The method of claim 20, wherein said earth formation includes at least one of rock, brine, hydrocarbon fluid and clay.

15 22. The method of claim 21, wherein said parameter which is determined forms the volume fraction of one of the hydrocarbon fluid and the brine.

# INTERNATIONAL SEARCH REPORT

International Application No  
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A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 G01V3/38 G01N33/24

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01V G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,4 398 151 (VINEGAR ET AL.) 9 August 1983 see the whole document ---	1,20
A	GEOPHYSICS, vol. 48, no. 9, September 1983, TULSA US, pages 1258-1268, XP002007681 BUSSIAN; A.E.: "Electrical conductance in a porous medium" see the whole document --- -/--	1,20

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents:

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Date of the actual completion of the international search

5 July 1996

Date of mailing of the international search report

01.08.96

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Bosma, R

# INTERNATIONAL SEARCH REPORT

Int. Application No  
PCT/EP 96/01234

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>JOURNAL OF APPLIED PHYSICS, vol. 58, no. 8, October 1985, NEW YORK US, pages 3236-3243, XP002007682 SHECHAO FENG, ET AL.: "Geometrical model of conductive and dielectric properties of partially saturated rocks" see the whole document -----</p>	1,20

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/EP 96/01234

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4398151	09-08-83	US-A- 4359687	16-11-82
		CA-A- 1161901	07-02-84
		FR-A,B 2474700	31-07-81
		GB-A,B 2068563	12-08-81
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